NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D C 20546

REPLY TO ATTN OF: GP

OCT 18 1973

(NASA-Case-MSC-13436-1) RESPIRATORY ANALYSIS SYSTEM AND METHOD Patent (Quantum Dynamics) 7 p CSCL 06B

N73-32015

Unclas 00/05 18170

TO: KSI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,759,249

Government or Corporate Employee : Quantum-Synamics, Inc. Tarzana, CA

Supplementary Corporate Source (if applicable) : —

NASA Patent Case No. : MSC-13,436-1

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

Yes [X] No [ ]

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words ". . . with respect to an invention of . . ."

Elizabeth A. Carter

Elizabeth A. Carter
Enclosure
Copy of Patent cited above

NASA-HQ

United States Patent [19]

Fletcher et al.

[11] **3,759,249**

[45] **Sept. 18, 1973**

[54] **RESPIRATORY ANALYSIS SYSTEM AND METHOD**

[76] Inventors **James C. Fletcher**, Administrator of the National Aeronautics and Space Administration with respect to an invention of; **Frederick F. Liu**, 17812 Community St, Northridge, Calif. 91324

[22] Filed **Aug. 19, 1971**

[21] Appl. No **173,190**

[52] **U.S. Cl.** .... **128/2.08**, 73/194 E, 73/194 M, 128/2 07

[51] **Int. Cl.** **A61b 5/08**

[58] **Field of Search** ... 128/2.08, 2 07, DIG 17, 73/194 R, 194 E, 194 M, 23 R, 195, 324/35, 324/36, 340/239

[56] **References Cited**

UNITED STATES PATENTS

3,523,529	8/1970	Kissen	128/2 07
3,396,719	8/1968	Taylor et al	128/2 07
3,577,984	5/1971	Levy et al	73/195 X
3,465,103	9/1969	Lynch	128/2 1 A X
3,572,331	3/1971	Kissen	340/239 R
3,507,146	4/1970	Webb	73/23
3,645,133	2/1972	Simeth et al	128/2 08 X
3,309,684	3/1967	Kahn et al	73/23 X
3,611,801	10/1971	Paine	128/2 08 X

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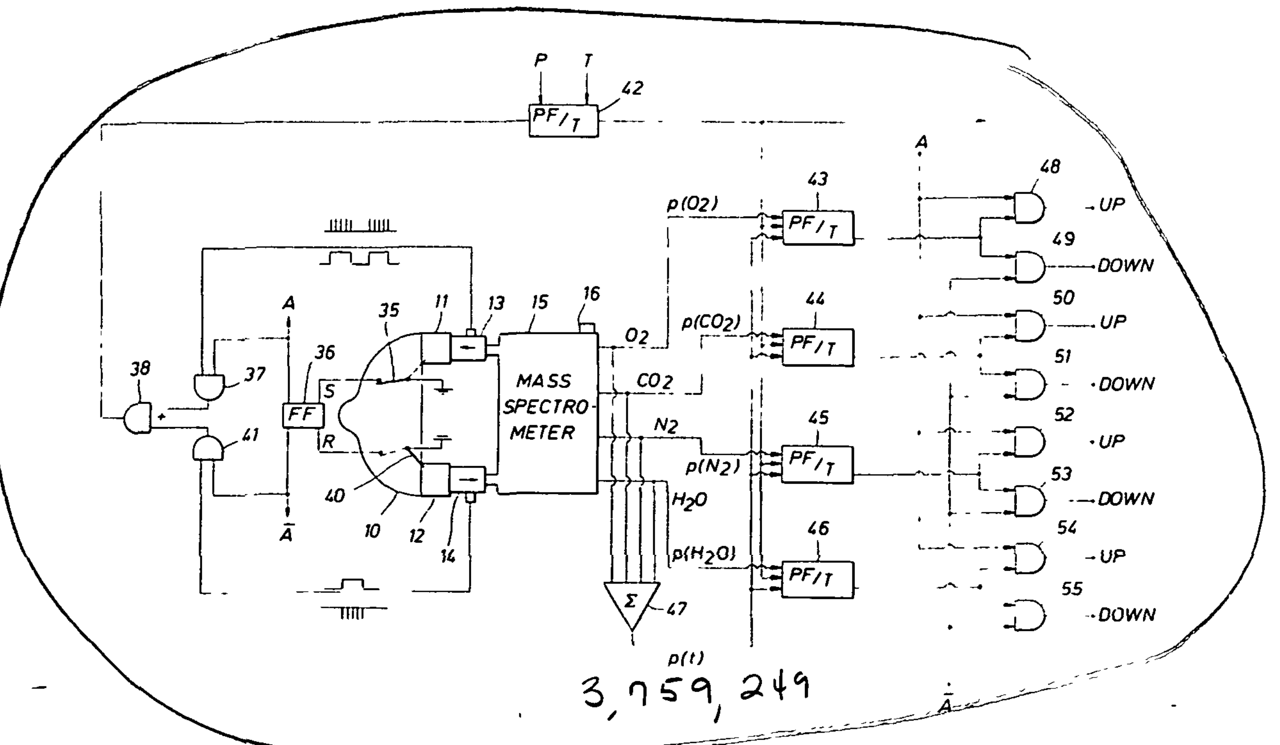
[57] **ABSTRACT**

A system for monitoring the respiratory process wherein the gas flow rate and the frequency of respiration and expiration cycles can be determined on a real time basis A face mask is provided with one-way inlet and outlet valves where the gas flow is through independent flowmeters and through a mass spectrometer The opening and closing of a valve operates an electrical switch, and the combination of the two switches produces a low frequency electrical signal of the respiratory inhalation and exhalation cycles During the time a switch is operated, the corresponding flowmeter produces electric pulses representative of the flow rate, the electrical pulses being at a higher frequency than that of the breathing cycle and combined with the low frequency signal. The high frequency pulses are supplied to a conventional analyzer computer which also receives temperature and pressure inputs and computes mass flow rate and totalized mass flow of gas From the mass spectrometer, components of the gas are separately computed as to flow rate as well The electrical switches cause operation of up-down inputs of a reversible counter To measure a real time, a 1-minute clock pulse is used to operate the counter The occurrence of a pulse alerts the counter, and the next succeeding reverse from down to up in the breathing cycle causes an electrical sequence to occur in which the counter is momentarily inhibited while the count therein is transferred to a printer The electrical sequence is complete before the next up-to-down reverse in the breathing cycle occurs, so that there is no loss in the counting of cycles. Thus, the number of cycles closest to one-minute time are measured The respective up and down cycles can be individually monitored and combined for various respiratory measurements

7 Claims, 4 Drawing Figures



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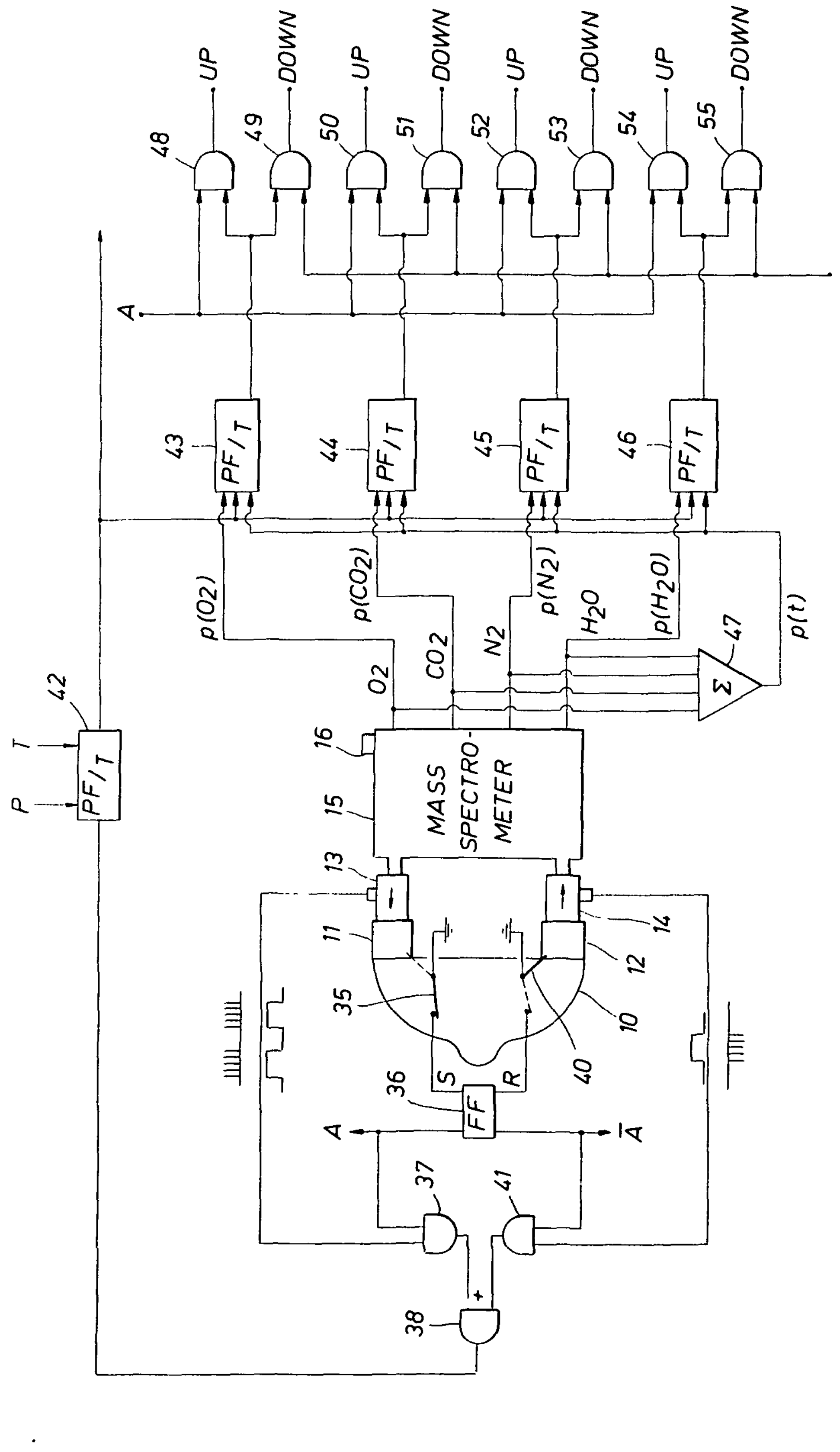


FIG.1

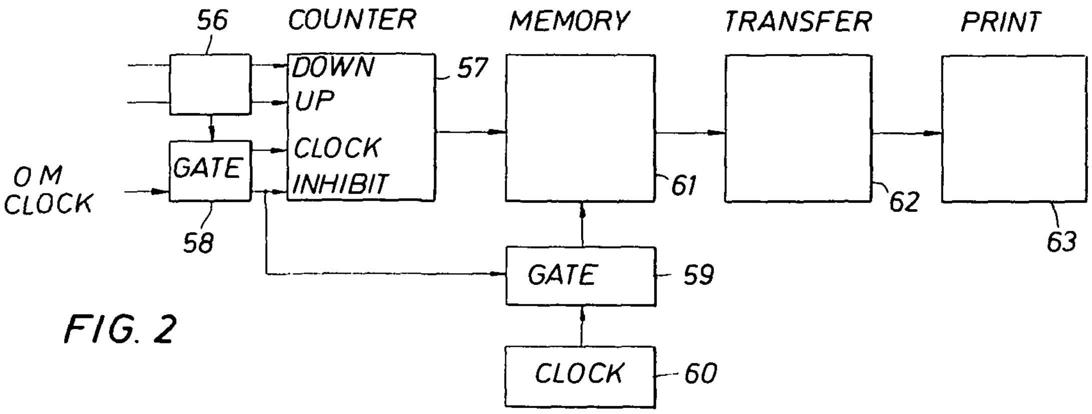
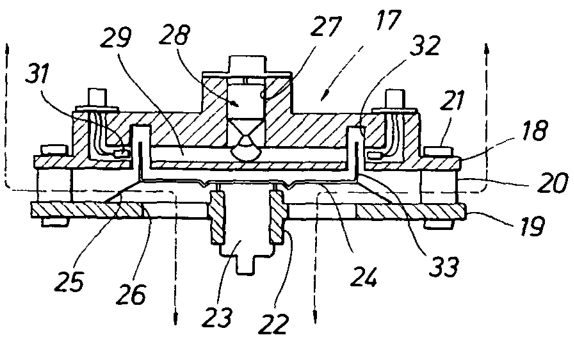


FIG. 2

FIG. 3



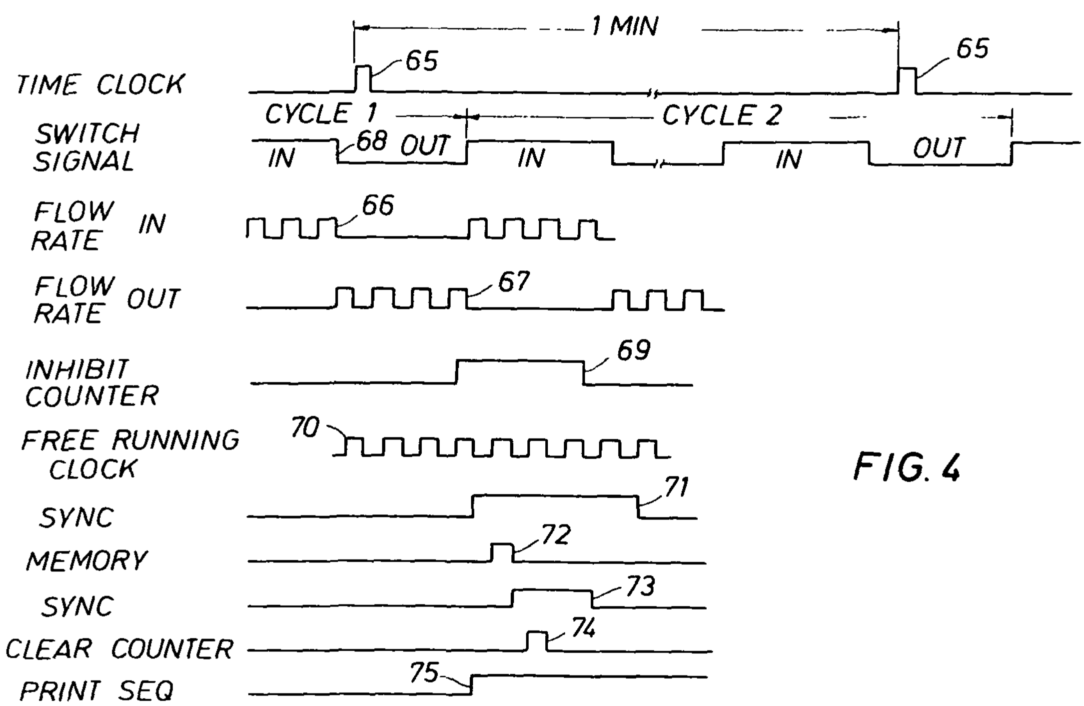


FIG. 4

RESPIRATORY ANALYSIS SYSTEM AND METHOD

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA Contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Statute 435, 42 USC 2457).

FIELD OF THE INVENTION

This invention relates to systems for quantitative analysis of the human respiratory process. In particular, it relates to methods and apparatus for obtaining an analysis of respiratory gas flow rate and frequency of inspiration and expiration cycles on a "real time" basis.

DESCRIPTION OF PRIOR ART

Prior art devices presently known are as follows

1. U.S Pat. No. 3,368,212 discloses a gas flow monitor for respiratory supervision In this sytem, thermistors are employed in an electrical circuit and used to monitor breathing. When gas flow fails, the thermistors trigger an alarm circuit

2 U.S Pat. No 3,201,988 and U.S. Pat No. 3,135,116 relate to turbine flowmeters to measure gas flow f

3. Elastronics Laboratories of Tarzana, Calif. sell a Model FPAC-100 Transient Flowrate Indicator and Electronic Frequency to Period-to Analog Computer used with flowmeters for accepting a pulse train signal and acting on the period T of each cycle to compute the inverse of the next time period $e_f = 1/T$ and hold the information for the next cycle.

4 Elastronics Laboratories of Tarzana, Calif sell a Model PF/T500 Mass-Flow Computer and Electronic Multiplier-Divider which computes mass flow rate and totalized mass flow of any gas or liquid providing a digital or analog output from an input frequency representing flow and analog voltages representing temperature and pressure

SUMMARY OF THE INVENTION

The human respiratory process is perhaps unique in that natural breathing varies in accordance with a person's physiological and metabolic condition and, of course, varies with physical conditions and activities. It is extremely important to respiratory physiologists, inhalation toxicologists, doctors and other biomedical workers to have a reliable analysis of the respiratory process and, particularly, to have an automated quantitative analysis of the respiratory process.

The respiratory process involves unrhythmic frequency in number of breaths per minute and gas flow rate in volume per unit time. The frequency (or periodicity) of breathing is a wave of alternating inspiration and exhalation cycles. By use of special switches which are operable by intake and outflow of gas, it is possible to obtain low frequency signals of the breath cycles. As will hereinafter be more fully explained, the breath cycles are correlated to "real time" intervals. During the inhalation and exhalation cycle, the flow rate is measured and quantalized as a pulse rate signal. The pulse rate signal is superimpose onto the alternating low frequency inspiration and expiration waveform. Thus, both flow and breathing cycles are combined in a single data channel.

In the present invention, the breathing cycle, as a low frequency signal, is separated between inspiration and exhalation portions, and each is counted and processed to provide accurate respiratory measurements For example, the uptake rate can be computed by subtracting the inspired flow quantity from the expired flow quantity during the same period. This can be accomplished by an up-down counter The function of "up" or inspiration portions can be accumulated as can the exhalation portions Consecutive counting of "up" and "down" portions of breathing cycles over a given period of time will give the desired uptake or expiration quantities

The synchronization of the respiratory process to time is accomplished by using a time reference such as a clock which emits a pulse each minute The control system to which the consecutive up-down pulses are supplied includes a counter for each parameter to be monitored In an up-down counter, for example, assuming the system is in operation, the counter will count the up and down pulses. When the 1-minute pulse is generated it alerts the counter, and on the next succeeding "up" pulse the counter is momentarily inhibited while the count on the memory therein is transferred to a printer Upon transfer, the inhibiting pulse is removed and the counter continues counting the pulses until the next 1-minute pulse appears As is obvious, the respiratory system thus produces measurements related to the 1-minute timing pulses.

The switches are of a design which generates an electrical signal at the instant inspiratory flow begins and turns off this signal when expiration starts or vice versa. In the respiratory measurement system, two valves are mounted in the face mask. One valve is open only to let in the fresh gas (air or oxygen) during the inspiratory period while the other valve opens only to vent expiratory flow. The valve has a diaphragm which is held closed by spring force and operated by a pressure differential. The pressure differential thus serves to open and close the valves When the valve diaphragm is lifted from its seat, a stem on the valve interrupts a light-beam between a light source and a photoelectric cell When this occurs, a negative electric pulse is generated which serves as a signal representative of the particular respiratory function.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference to the drawings will further explain the invention wherein like numerals refer to like parts, and in which:

FIG 1 is a schematic and functional illustration of an overall system including a mask and computers for obtaining flow rate and frequency of breathing indications,

FIG. 2 is a schematic and functional illustration of a typical counter system for counting respiration frequency in terms of real time,

FIG. 3 is a functional representation of a valve aned switch for obtaining signals indicative of the breathing functions; and

FIG 4 is a timing diagram for illustrating a logic sequence for obtaining typical measurements.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, a system is illustrated for a "physiological clock of respiration " The system includes a face mask, schematically and generally indicated by the numeral 10. The face mask 10 has an inlet or inspiratory valve 11 and an outlet or expiratory valve 12. Valves 11 and 12 are one-way valves arranged so that flow is into the mask 10 via valve 11 and out from the mask 10 via valve 12. Valves 11 and 12 are respectively coupled to flowmeters 13 and 14 which, in turn, open into a mass spectrometer 15 with a flow conduit 16. Gas flow is into the mask 10 via conduit 16, spectrometer 15, flowmeter 13 and valve 11 and out of the mask 10 via valve 12, flowmeter 14, spectrometer 15 and conduit 16. Valves 11 and 12 are normally closed and operated by virtue of differential pressure caused by inhalation or exhalation of gas

Referring now to FIG. 3, a typical flow valve 17 includes upper and lower plate members 18 and 19 which are spaced from one another by circumferentially disposed spacers 20 and attached to one another by fasteners 21. The lower plate 19 has a central alignment hub 22 which receives an alignment stub 23 attached to the center of a diaphragm 24. About the hub 22 are perforations 26 so that gas may flow through the perforations and between the plates The diaphragm 24 is cylindrically formed and is constructed of a thin flexible material such as rubber or plastic. The diaphragm has a peripheral conically-shaped portion 25 arranged to make contact with the upper surface of lower plate 19. The arrangement is such that the diaphragm 24 has a spring force tending to hold it in contact with the lower plate. Thus, if the valve is inserted into the face mask with hub 22 facing in one direction, exhalation gas may flow through the perforations 26 and between the plates 18 and 19. With the valve facing in an opposite direction, inhalation gas similarly is passed through the perforations 26 and between the plates 18 and 19.

In the upper plate 19 is a central cavity 27 containing a light source system 28. Communication passages 29 from the light source 28 extend to cavities respectively containing photoelectric cells 31. Thus, the cells 31 can be activated by the light source 28. The upper plate 18 has recesses 23 which traverse the communication passages 29 and receive an upwardly extending extension 33 on the diaphragm 24. In the normally closed position of the diaphragm, as illustrated, openings (not shown) in the diaphragm permit light to pass from the source 28 to a cell 31. When gas flow moves the diaphragm 24, the openings in the extensions are transported from registry with the light beam, and interruption of the light beam deactivates the cell 31 to enable production of an electrical signal

Referring now to the system illustrated in FIG. 1, during inhalation, valve 11 is open and valve 12 is closed While valve 11 is open, the flowmeter 13 will produce an electrical signal having a frequency dependent upon the inhalation flow rate. At the same time, a normally open electrical switch 35 is closed by operation of the valve 11 to provide a ground potential to set a flip-flop 36. Switch 35 corresponds to the light beam switch previously described with respect to FIG. 3. When the flip-flop 36 is set, a d.c. gating signal "A" conditions a NAND gate 37. The NAND gate 37 is also connected to the output of the flowmeter 13 so that the signals from the flowmeter are passed to another NAND gate 38. Thus, during inhalation the period of the switch operation defines the inhalation cycle, and the flow rate is established by the frequency of the flowmeter pulses during the period.

During exhalation, valve 12 is open and valve 11 is closed. While valve 12 is open, the flowmeter 14 similarly will produce an electrical signal having a frequency dependent upon the exhalation flow rate At the same time, a normally open electrical switch 40 is closed by operation of the valve 12 to provide a ground potential to reset the flip-flop 36. When the flip-flop is reset, a d c. gating signal $\overline{A}$ conditions a NAND gate 41. The NAND gate 41 is also connected to the output of flowmeter 14 so that the signals from the flowmeter are passed to the NAND gate 38.

During the inhalation period, while the exhalation valve 12 is in closed position, the corresponding electrical switch 40 is open Since the flip-flop 36 is in a "set" positon and the NAND 41 is connected to the other terminal of the flip-flop 36, signals from flowmeter 14 cannot pass through the NAND 41. Thus, during the inhalation period, the inhalation signal from the flowmeter 13 is passed through NAND 37 and 38 to the computer This condition prevails unti the inhalation is complete and exhalation begins, whereupon switch 35 is opened and switch 40 is closed When switch 40 closes, the flip-flop 36 is "reset" which causes a d c. potential at terminal $\overline{A}$ to open the NAND gate 41, permitting the flowmeter frequency signals to pass through NAND 41 and 38 to the computer.

With the foregoing system the inhalation and exhalation flows are readily segregated, and the breathing frequency or period can be readily calculated. From the flow rate frequency, the total flow volume for inhalation and exhalation can easily be determined. Moreover, the frequency of breathing and flow rate are not integrated into a single electrical signal system containing all of the respiratory information, and this signal system can be correlated with a timing factor.

The flow rate signal for inhalation or exhalation, or both, can be re-separated, so that the flow rate can be computed with any and all of its corresponding partial pressure signals from the mass spectrometer 15.

In the operation of the system, the inhalation of gas produces a train of electrical pulses which are a linear function of the inhalation flow, and the exhalation of gas produces a train of electrical pulses which are representative of the exhalation flow. The successively occurring trains of pulses which represent total flow are sent from the NAND circuit 38 to a conventional mass flow computer 42. With the input of an absolute pressure signal P and an absolute temperature signal T, the total volumetric flow rate as determined from computer 42 can be applied simultaneously to one of the input terminals of four or more computers 43–46. Each of the computers 43–46 receives from the spectrometer 15 the percentage concentration (or partial pressure in percent) of O_2, CO_2, N_2 or H_2O as its other input. The partial percentages are also summed by a summing network 47 and applied as an input to computers 43–46. As a result, the respiratory flow rate caused by O_2, CO_2, etc., can be determined at any time.

To compute the up-take rate of O_2, or the release rate of CO_2, for example, the outputs of the computers 43–46 can be re-separated. This is accomplished by coupling the inputs of "up" and "down" NAND gates 48–55 to respective computers for determining the status of the components The up and down NAND gates, respectively, are also coupled to the flip-flop 36 so that "A" and "$\overline{A}$" steering outputs are applied to the gates Thus, computers coupled to the up and down inputs can be used to provide an indication of the breathing function of the separate components in any detail desired

Turning now to FIG 2, the respective signals for up and down signals are supplied to a circuit 56 which conveys the respective signal to a reversible BCD counter 57 and to a gate circuit 58. The gate circuit receives clock pulses which are spaced at 1-minute intervals Upon the occurrence of a one-minute clock pulse, the counter 57 is set or alerted to be synchronized with the breathing function. When the transition from "up" to "down" next occurs after the 1-minute alert pulse, the signals applied to the gate actuate it to inhibit the counter and actuate another gate 59. Gate 59 is coupled to a high frequency clock 60 which applies a clocking pulse to the memory that effects a transfer of the stopped count in the counter 57 to the memory 61 and transfer of the count in the memory by a transfer circuit 62 to a print system 63. The inhibit and transfer function occur in less time than it takes to count a single flowmeter output pulse so that no measurement function is discontinued prior to the beginning of the count of "up" pulses by the counter 57. Thereafter, the counter 57 accepts the "up" and "down" pulses until the next 1-minute pulse to the gate 58 alerts the counter so that the next "up" transition repeats the operation. Thus, it will be apparent that the "up" and "down" counting is governed by the number of complete breath cycles occurring relative to a 1-minute timing cycle

A timing diagram is illustrated in FIG. 4 which is more fully illustrative of the technique. In FIG 4, timing pulses 65 occur at 1-minute intervals The operation of switches 35 and 40 of FIG. 1 produce the gating voltages A and $\bar{A}$ which operate the up and down gates for the counters. The flow rate "in" and "out" is a high frequency signal such as typically illustrated at 66 and 67. As such, the higher frequency signals can be compressed with the switch signals such as illustrated at 68. At the instant the respiratory function changes function from exhalation to an inhalation, the corresponding switch signal triggers a sync signal 69 to inhibit the counter. The sync signal 69 has a lesser period than ordinarily expected for an inhalation period. Thus, during an inhalation cycle, the counter is inhibited

A free-running, high-frequency clock signal 70 is used to cause generation of another sync signal (identified as 71) with the generation of the next succeeding clock pulse 70. The sync pulse 71 and the next succeeding clock pulse 70 produces a memory pulse which causes transfer gates to open and the counts from the counter to be dumped into the printer memory Another sync pulse 73 is generated so that a clear counter pulse 74 can reset the counters. A print sequence pulse 75 is generated simultaneously with the sync pulse 71.

One of the advantages of the present invention is that numerous measurements can be accomplished accurately on a strict 1-minute, half-minute, breath-by-breath or other period basis. The common measurement of breath is the so-called T_M mode, where T_M is the period of time required to encompass a series of complete breath functions measured from a starting point on the breath waveform to a corresponding point after a time of approximately 1 minute. Thus it will be readily apparent that the counting function of the foregoing described function of the foregoing described system is regulated by the 1-minute pulses, and the T_M is governed precisely by the breath arrivals

Further modifications and alternative embodiments will be apparent to those skilled in the art in view of this description, and, accordingly, the foregoing specification is considered to be illustrative only.

What is claimed is

1. Apparatus for monitoring the respiratory function comprising

respiratory means for receiving inhalation and exhalation gas flow, said respiratory means having inhalation and exhalation valve means respectively operative for opening in response to inhalation and expiration, said respiratory means including means for developing electrical signals representative of the respiratory functions,

first computing means connected to the output of the respiratory means and also receiving signals indicative of absolute pressure and temperatures for providing a signal indicative of mass flow rate,

analyzing means determining the partial pressures of selected respiratory gases,

summing means receiving the partial pressures from the analyzing means and providing a signal representative of total pressure,

second computing means connected to the output of first computing means, the signal of partial pressure of a selected gas and the signal from the summing means to provide a signal representing mass flow of selected respiratory gas; and

first counter means connected to the second computing means and also receiving signals of inhalation and exhalation cycles to produce a signal indicative of net difference of selected respiratory gas

2. The apparatus of claim 1 wherein there is a second counter means connected to the first counter means,

timing means for controlling the second counter means by providing timing signals, said timing signals defining a finite time reference for the respiratory function;

means responsive to said timing signals for stopping the measurement of the respiratory function and nearly simultaneously reinitiating a new measurement of the next respiratory function; and

means for transferring the counted data from said counter means to a storage means without affecting the measurement then underway thereby synchronizing the unrythmic respiratory phenomenon to a finite timing means so that each measurement begins and ends at the beginning of a respiratory function after the occurrence of the timing signal from the timing means

3. The apparatus of claim 2 including a free running, high frequency clock to provide discrete time elements to the measurement.

4. The apparatus of claim 2 and further including means operative during the inhibition time period for printing the output of said counter means

5. The apparatus of claim 1 wherein said valve means includes a flow passage and a pressure differential operated diaphragm in said flow passage, and means responsive to movement of said diaphragm for generating an electrical signal.

6. A method for monitoring the respiratory process wherein the gas flow rate and the frequency of inhalation and exhalation cycles are determined on a real time basis, said method comprising:

deriving alternating low frequency signals of the inhalation and exhalation cycles,

measuring as pulse rate signals the flow rate during the inhalation and exhalation cycles,

converting the pulse rate signals and frequency signals to up and down signals representing inhalation and exhalation flow rate,

supplying the up and down signals to a continuous counter; and

providing to the counter a timing signal defining a finite time which alerts the counter to be synchronized with the respiratory function whereby upon the next transition of the respiratory cycle the counter commences counting and continues to count until the next similar transition of the respiratory cycle after the succeeding timing signal at which time the counted data is transferred while the count is continued

7. The method specified in claim 6 wherein a free-running, high-frequency clock signal is applied to the counted data

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